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Power System Stability Improvement through Multilevel Optimal Control Strategy

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ABSTRACT
This paper presents a multilevel optimal control scheme (strategies) for interconnected power systems. A large-scale power system may be viewed as an interconnection of several subsystems, with possible change of interconnection pattern during operation. The control strategy is based on optimization of large-scale systems composed of a number of subsystems. Local controller is used to optimize each subsystem, ignoring the interconnection. Then, a global controller may be applied to minimize the effect of interconnections and improve the performance of the overall system. An optimal state feedback control and robust pole placement are also presented for a comparison. The simulation results for a multimachine power system consisting of two machines show the effectiveness of the proposed control strategy.
Keywords: *Power system stability, multilevel optimal control, multimachine systems*

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I. INTRODUCTION

An interconnected power system consisting of a complex combination of power plants, substations, transformers, transmission lines, and distribution systems that supply electricity to urban, business and industrial loads. In addition, there are smaller independent electricity networks that provide power to islands or remote areas, which have limited or no access to interconnected public networks. Power systems have been growing in size and complexity with increasing interconnections between systems. In recent years, there has been considerable interest in the application of optimal control to develop multimachine stabilization technique [1] with the objective of extending the dynamic stability boundaries of synchronous machines and satisfying increasingly complex control needs. In such applications, optimal stabilizers were designed via the optimal linear regulator theory using measurements from all the system generators [2]. However, the computation of an optimal controller becomes extremely difficult and time consuming as the order of the system increases. For an nth-order system it is necessary to solve $n(n+1)/2$ Riccati equations in order to calculate the controller gain. To overcome these difficulties, multi-controller structures, in which each controller acts on a different part of the information space of the system under control, are used.

This paper is concerned with the development of multilevel optimal control to interconnected power system. The development of suitable controller involves extensive modeling and simulation of the power systems. The overall power system is decomposed into separate subsystems, each subsystem comprising one machine. At the subsystem level, an optimal feedback controller is derived by state feedback of each machine. The controllers thus determined at the subsystem level depend only on local information pertaining to the particular machine. In order to take into account the interaction between the different subsystems, a global controller is designed at the higher level [3]. At this level, all subsystems will transfer the necessary information to achieve the global objectives. Many studies have been developed to improve the stability of the power system, including control based on the heuristic optimization approach [4, 5], robust control [6], and dSPACE simulator to identify the characteristics of the multimachine system [7].

The control strategy proposed here is applied to a 2-machines 3-buses power system. The simulation results of the study are presented to demonstrate the effectiveness of the proposed controller. A comparison between the performance of the proposed controller and that optimal state feedback control [8] and robust pole placement [9] are also included.

II. PROBLEM FORMULATION

A multimachine interconnected system S can be described by linear model of the form,

$$S: \quad \dot{x} = Ax + Bu \tag{1}$$

where x is an n-dimensional state vector and u is an m-dimensional control vector. A and B are constant matrices of appropriate dimensions. The system in equation (1) can be considered to be composed of N interconnected subsystems, each subsystem S_i, being described as

$$S_i:\quad \dot{x}_i = A_i x_i + B_i u_i + h_i(x) \tag{2}$$

such that,

$$h_i(x) = \sum_{\substack{i=1 \\ j \neq i}}^{N} A_{ij} x_j \tag{3}$$

The performance of each subsystem is measured when the quadratic cost,

$$J_i = \tfrac{1}{2}\int_0^{\infty} \left\{ (x_i)^T Q_i x_i + (u_i^l)^T R_i u_i^l \right\} dt$$

(4)

Attain is minimum value when an optimal control u_i^l is applied to each subsystem. Q_i and R_i are symmetric positive semidefinite and positive definite matrices, respectively.

III. CONTROL STRUCTURE

In order to stabilize the overall system S, we apply a multilevel control strategy of the form,

$$u_i = u_i^l + u_i^g \tag{5}$$

where u_i^l is a local feedback control vector assuming no interactions between subsystem S, i.e. $h(x) = 0$ and u_i^g represents a global control signal that compensates for the effect of the presence of coupling.

The optimal u_i^l minimizing equation (4) can be determined as,

$$u_i^l = -K_i^l x_i$$

(6)

$$K_i^l = R_i^{-1} B_i^T P_i \tag{7}$$

where P_i is solution of Riccatii equation:

$$(A_i)^T P_i + P_i A_i - P_i B_i R_i^{-1} (B_i)^T P_i + Q_i = 0 \tag{8}$$

The global signal u^g is determined such that,

$$B.u^g + Zx = 0 \tag{9}$$

where

$$Z_{ij} = A_{ij} \quad ;\ i \neq j$$
$$= 0 \quad ;\ i = j \tag{10}$$

and,

$$u^g = -B' Zx \tag{11}$$

where B' is the pseudo-inverse of B, defined as

$$B' = [B^T B]^{-1} B^T$$

Thus

$$u^g = -[B^T B]^{-1} B^T Zx$$

(12)

where $G = B'Z = [B^T B]^{-1} B^T Z$ is so called the global gain matrix.

Figure 1 shows the communication network required for the exchange of information using such a hierarchical technique.

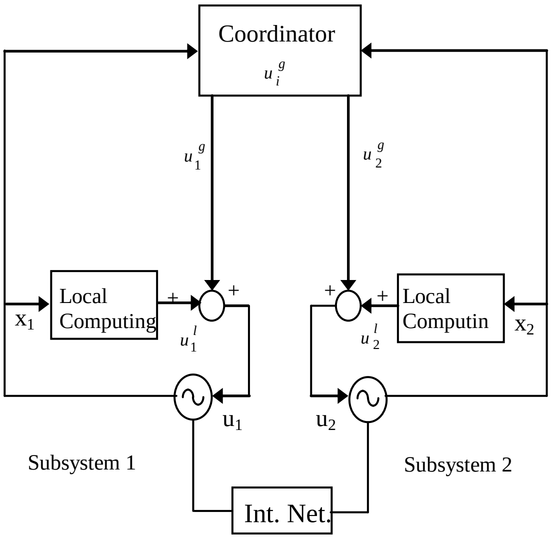

Figure 1. Communication network for computing global law

IV. RESULTS AND DISCUSSION

To assess the proposed method in the case of multimachine system, the system shown in the Figure 2, taken from [10], is studied.

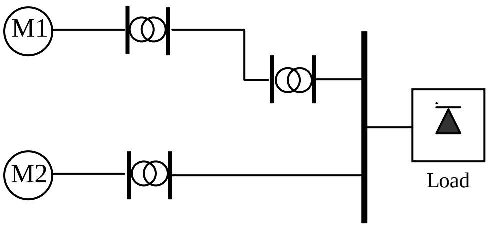

Figure 2. Multimachine system [10]

The model used refers to equation (1), as follows:

$$\dot{x} = Ax + Bu$$

where $x^T = [\Delta\omega_1\ \Delta\delta_1\ \Delta e'_{q1}\ \Delta e_{FD1}\ \Delta\omega_2\ \Delta\delta_2\ \Delta e'_{q2}\ \Delta e_{FD2}]$

$$A = \begin{bmatrix} -0.244 & -0.0747 & -0.1431 & 0 & 0 & 0.0747 & 0.0041 & 0 \\ 377 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.046 & -0.455 & 0.244 & 0 & 0.046 & 0.13 & 0 \\ 0 & -398.56 & -19498.8 & -50 & 0 & 398.58 & -3967 & 0 \\ 0 & 0.178 & -0.0433 & 0 & -0.2473 & -0.178 & -0.146 & 0 \\ 0 & 0 & 0 & 0 & 376.99 & 0 & 0 & 0 \\ 0 & 0.056 & 0.1234 & 0 & 0 & -0.0565 & -0.3061 & 0.149 \\ 0 & -677.39 & -10234.22 & 0 & 0 & 677.78 & -13364.16 & -50 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 25000 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 25000 \end{bmatrix}^T$$

The eigenvalues of the original system are given in Table 1. The modes that should be retained are the modes -0.0904 ± j 9.8430, -0.0006, and -0.2443, respectively.

Table 1: System eigenvalues

-25.1741±j67.8187	-0.0006
-25.2329±j30.3073	-0.2443
-0.0904 ±j9.8430	

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The multilevel controller in this section will be compared with robust pole placement controller and optimal state feedback controller.

In the robust pole placement simulations, it is desired to remove the original eigenvalues in the sets of eigenvalues K1 and K2, as shown in Table 2. The transient responses of the angular frequencies with and without global control are shown in Figure 3. The transient responses of the angular frequencies to a 5 % change in the mechanical torque of machine 1 (all controller) are shown in Figure 4.

Table 2: System eigenvalues and desired eigenvalues

Open-Loop	K1	K2
-25.1741±j67.8187 -25.2329±j30.3073 -0.0904 ±j9.8430 -0.0006 -0.2443	-25.1741±j67.8187 -25.2329±j30.3073 -2.0904±j9.8430 -2.0006 -2.2443	- 25.1741±j67.8187 - 25.2329±j30.3073 -4.0904±j9.8430 -4.0006 -4.2443

The overall system eigenvalues are given in Table 3. It is shown, that the relative stability of the proposed method is much better than other.

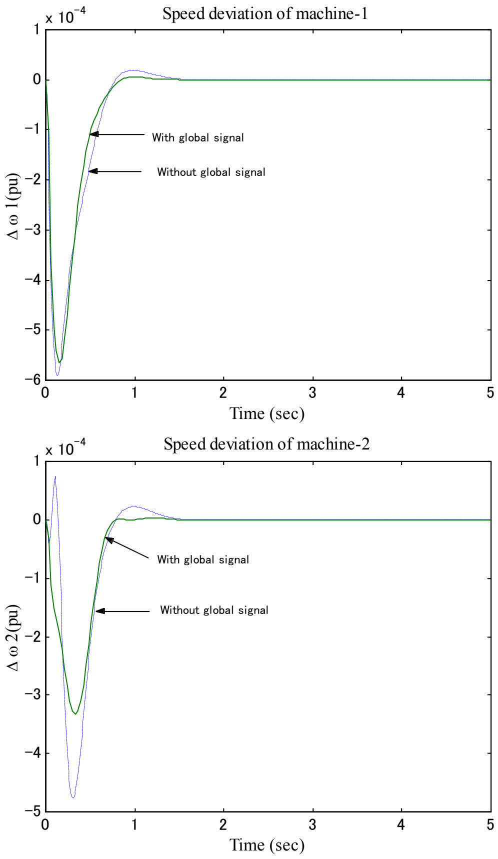

Figure 3. Transient responses with and without global control

Table 3: System eigenvalues.

Open-Loop	Optimal Control	Multilevel Control
-25.1741±j67.8187	-25.4947±j67.9481	-25.2335±j64.4124
-25.2329±j30.3073	-25.7861±j30.7483	-25.1817±j37.0836
-0.0904±j9.8430	-2.1329±j10.1152	-4.8862±j11.4038
-0.0006	-3.3733±j3.1807	-5.4999±j3.7619
-0.2443		

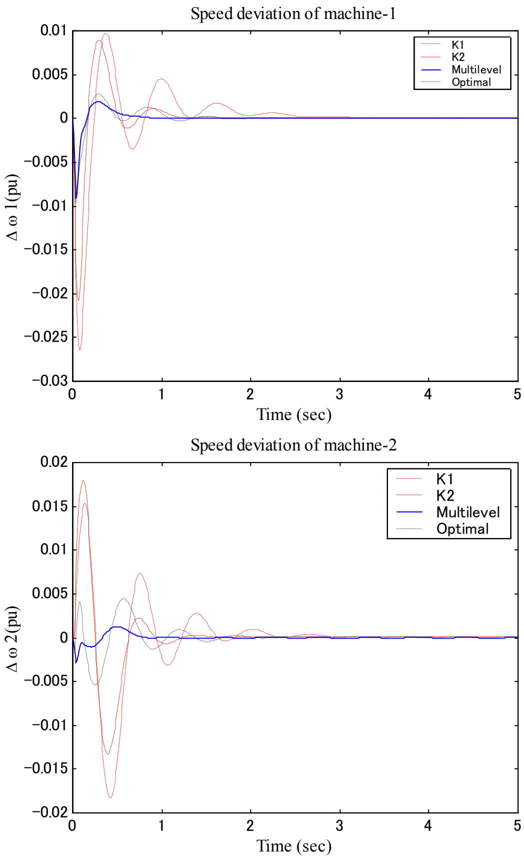

Figure 4. Transient response following a 5% change in the mechanical torque of machine 1

V. CONCLUSION

In this paper a multilevel control scheme for interconnected power system has been presented. The control configuration consists of two levels, where optimization is carried out on both the subsystem and overall system level. On the subsystem level, local controllers are chosen to optimize subsystem performance indices, totally disregarding the interconnections among the subsystems. On the overall system level, a global controller is implemented to minimize the effects of interconnections. The simulation results showed that the dynamic performance of multimachine power systems have been enhanced by multilevel controller. The robust pole placement required a large signal control to obtain a similar performance with optimal control.

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